ERDC/TN EEDP-04-37
June 2007

Overdepth Dredging and Characterization Depth Recommendations

by John F. Tavolaro, Joseph R. Wilson, Timothy L. Welp, James E. Clausner, and Angela Y. Premo

PURPOSE: This technical note (TN) describes the excavation accuracy of various dredges under different project conditions, and provides guidance to U.S. Army Corps of Engineers (USACE) personnel in determining depths to adequately characterize and evaluate material to be dredged in the entire dredging prism, including paid allowable overdepth and non-pay dredging. The technical note also improves communication on these subjects with other agencies and the public. Proper selection of characterization depths, considering the dredge's excavating accuracy and respective project-specific conditions, is critical to ensure future compatibility of the dredging description and quantities in environmental compliance documentation with the dredging as actually implemented. This guidance is meant to supplement Engineer Regulation (ER) 1130-2-520 (USACE 1996) and the Memorandum for Commanders, Major Subordinate Commands, "Assuring the Adequacy of Environmental Documentation for Construction and Maintenance Dredging of Federal Navigation Projects" (USACE 2006). Much of the information from the USACE 17 Jan 2006 Memorandum is included in this technical note.

BACKGROUND: It is USACE policy that dredging will be accomplished in an efficient, cost-effective, and environmentally responsible manner to improve and maintain the Nation's waterways to make them suitable for navigation and other purposes consistent with Federal laws and regulations (USACE 1996).

In a guidance memorandum dated 17 January 2006, Congress specifically authorizes Federal navigation channels with a specific depth and width (and length) (USACE 2006). The authorized depth and width (Figure 1) are generally based on maximizing net transportation savings considering the characteristics of vessels using the channel. In addition to authorized dimensions, channel reliability is considered and may result in the incorporation of advance maintenance depths into construction of the channel where such advance maintenance is justified to ensure channel reliability and least overall cost. There are inherent excavation inaccuracies in the dredging process. Excavation accuracy relates to closeness of the dredge's completed work to the design (project and/or overdepth) grade (Figure 1) as determined by an after-dredge hydrographic survey.

Dredge excavation accuracies vary as a function of type of dredging equipment used (mechanical or hydraulic) and interaction with site-specific physical conditions (tides, currents, waves), type and thickness of sediment or rock being dredged, and channel design (water depth, side slopes, etc.). Because of these variables and the resulting excavating inaccuracies associated with the dredging activity, USACE engineering design, cost estimating, and construction contracting documents recognize that dredging below the Congressionally authorized project dimensions

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 2007	**N/A**	**-**

4. TITLE AND SUBTITLE	
Overdepth Dredging and Characterization Depth Recommendations	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Engineer Research and Development Center Vicksburg, MS**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**32**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

will occur and is necessary to ensure required depth and width as well as cost-effective operability. To balance project construction requirements against the need to limit dredging and disposal to the minimum required to achieve the designed dimensions, a paid allowable overdepth (including side slopes) is incorporated into the project dredging prism (Figure 1). Material removed from this allowable overdepth is paid for under the terms of the dredging contract. Material removed beyond the limits of allowable overdepth is not paid for (USACE 2006).

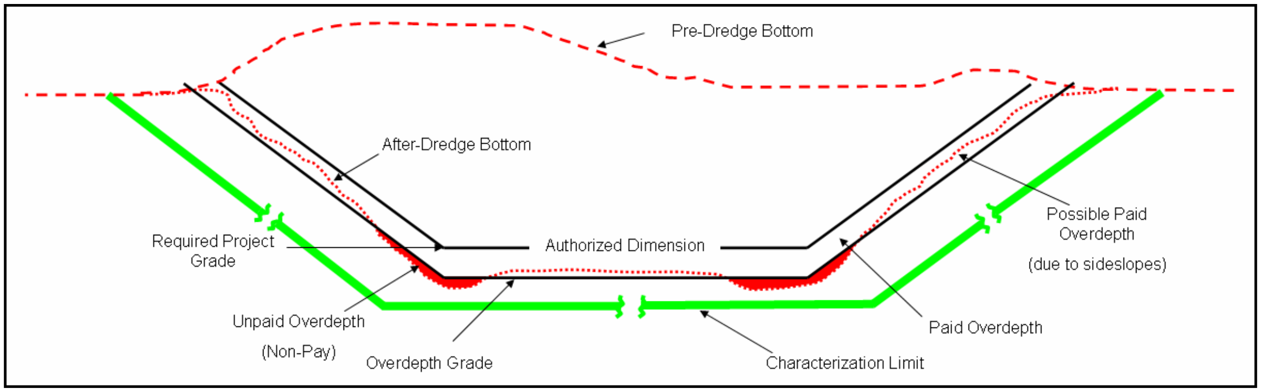

Figure 1. Various dredging prism dimensions and zones.

The dredging zones shown in Figure 1 are defined and discussed in more detail below (for clarity purposes, advance maintenance has not been included in this figure). This information is primarily excerpted directly from USACE (2006).

- **Authorized Dimensions.** Authorized dimensions are the depth and width of the channel authorized by Congress to be constructed and maintained by USACE. These authorized channel dimensions are generally based on maximizing net transportation savings considering the characteristics of vessels using the channel and include consideration of safety, physical conditions, and vessel operating characteristics. For entrance channels from the ocean into harbors, the authorized dimensions often include an additional allowance of safety for wave action for that portion of the channel crossing the ocean bar. For example, a 45-ft entrance channel may have an authorized 47-ft depth over the ocean bar.

- **Advance Maintenance.** Advance maintenance is dredging to a specified depth and/or width beyond the authorized channel dimensions in critical and fast shoaling areas to avoid frequent re-dredging and ensure the reliability and least overall cost of operating and maintaining the project authorized dimensions. For maintenance dredging of existing projects, Major Subordinate Commanders (MSC) (Division Commanders) are authorized to approve advance maintenance based on written justification. For new navigation projects, advance maintenance is approved as part of the feasibility report review and approval process based on justification provided in the feasibility report.

- **Paid Allowable Overdepth.** Paid allowable overdepth dredging (depth and/or width) is a construction design method for dredging that occurs outside the required authorized dimensions and advance maintenance (as applicable) prism to compensate for physical

conditions and inaccuracies in the dredging process and allow for efficient dredging practices. The term "allowable" must be understood in the contracting context of which dredging quantities are eligible for payment, rather than in the regulatory context of which dredging quantities are reflected in environmental compliance documents and permits. Environmental documentation must reflect the total quantities likely to be dredged including authorized dimensions, advance maintenance, allowable overdepth, and non-pay dredging. The paid allowable overdepth should reflect a process that seeks to balance consideration of cost, minimizing environmental impact, and dredging capability considering physical conditions, equipment, and material to be excavated. ER 1130-2-520 (USACE 1996) provides that District Commanders may authorize dredging of a maximum of 2 ft of paid allowable overdepth in coastal regions and in inland navigation channels. Paid allowable overdepth in excess of those allowances or the use of zero paid allowable overdepth requires the prior approval of the MSC Commander. USACE recognizes that there may be circumstances where there is a need for increased excavation accuracy in the dredging process, for example in environmental dredging of contaminated material, which dictate trading potential increased costs for a reduction in paid allowable overdepth, i.e., reducing the quantity of material required for special handling/placement or treatment.

- **Non-pay Dredging.** Non-pay dredging, also known as non-paid overdepth, is dredging outside the paid allowable overdepth that may and does occur due to such factors as unanticipated variation in substrate, incidental removal of submerged obstructions, or wind or wave conditions that reduce the operators' ability to control the excavation head. In environmental documentation, non-pay dredging is normally recognized as a contingency allowance on dredging quantities, and may and does occur in varying magnitude and locations during construction and maintenance of a project.

- **Sediment Characterization:** Sediment characterization is the process of identifying and evaluating the characteristics of sediments to be dredged for the purpose of predicting environmental impacts due to dredging and/or disposal activities. It can take the form of physical, chemical, or biological sampling and/or testing, or any combination of these three forms of characterization. The extent of sediment characterization – physical, chemical, or biological - necessary to ensure compliance with applicable environmental laws and regulations is site-specific and should be developed by USACE after considering all site-specific variables that might influence the ultimate channel prism dredged.

- **Characterization Depth.** Characterization and evaluation of dredged material must consider the entire dredging prism, including paid allowable overdepth and non-pay dredging. Thus the characterization depth is the maximum depth to which material can be reasonably expected to be removed intentionally or otherwise. The characterization depth will be described by the USACE in appropriate National Environmental Policy Act (NEPA) and Clean Water Act (CWA) environmental compliance documents.

- **Required Project Grade.** This is the minimum depth specified by the Corps for each dredging project or specific reach within a project. Often it is the federally authorized depth, but in some cases can be less or more (for example, when advance maintenance

has been authorized). This is the minimum depth that all the material must be dredged to clear grade.

Side slopes may be dredged by either dredging along the slope of the required dimension, or by dredging an equivalent box cut at the base of the side slope for the required dimension. A box cut is a typical excavation method made by the dredge during a swing or pass where the width of cut is sufficient to allow slope material to slough off (or cave) to the natural underwater repose of that material without encroaching the desired channel dimensions. Slope material can cave in and be excavated while the dredge is working, or the material can cave in gradually, and be excavated during a later dredging project. The appropriate characterization depth, and resultant horizontal component from the side slopes, must be selected so this material will also be characterized and evaluated with regard to its suitability for the proposed placement of the material.

The following provides background on the requirements to adequately characterize all dredged material that could be removed during a Federal dredging project. In collaboration with appropriate State and Federal resource and regulatory agencies, USACE will ensure that all applicable environmental compliance actions required for the dredging project have been identified and coordinated with those respective agencies. The Corps will characterize the total dredging prism of the dredging project, including authorized project dimensions, advance maintenance, paid allowable overdepth, and anticipated non-pay dredging.

Environmental documentation must describe the dredging project appropriate to the level of detail reasonably available at the stage of the project development process and present the dredging parameters, including the advanced maintenance, paid allowable overdepth, and non-pay dredging quantities, and the maximum depth and width that was characterized and evaluated for dredging and placement.

The dredging quantities reflected in environmental documentation prescribe the estimated quantities to be dredged and placed. The estimates must be adequate to ensure achievement of the full dimensions of the Congressionally authorized project and advance maintenance needs including estimates of the quantity that may be excavated due to the inherent imprecision of the dredging process while limiting dredging quantities in the interest of environmental protection and preservation of disposal (placement) capacity.

DETERMINATION OF DREDGE EXCAVATION ACCURACIES AND ADEQUATE CHARACTERIZATION DEPTHS: As noted in the "information background" section from the 17 January 2006 memorandum (USACE 2006), appropriate characterization of the dredged material is important in evaluating the impacts of the disposal (placement) of the dredged material and the quality of the environment in the channel after dredging is completed. If overdepth dredging is not properly described and characterized, potential environmental impacts will not be properly addressed. Sediment characterization should include the total amount of material that may be dredged, so as not to under-represent or miss the nonpay (unpaid) overdepth dredged material. Also, the quality of the sediment that is exposed after the dredging is completed may not be properly characterized if the total amount of material that could be dredged is not evaluated. This could lead to possibly erroneous conclusions concerning the effects to aquatic biota from dredging the channel. Finally the quantity of dredged material

directly correlates to physical impacts to the environment at the placement site – the more sediment, the greater the possible impact. If the quantity of overdepth dredging is not properly estimated, it could lead to misleading conclusions concerning the environmental impacts that may occur at the disposal site (Tavolaro and Weinberg 2006).

There is a scarcity of quantitative data to answer questions on dredge excavation accuracies in different project conditions and how to determine adequate characterization depth. Aspects to be considered in answering these questions include how much overdepth dredging is to be expected, given the specifics of a particular project design and dredge, and what depth for characterization is deemed as adequate?

While data are limited, the problems noted above require guidance on estimating characterization depths. This technical note is intended to provide additional clarification and supplement the January 2006 guidance.

Prior to providing the specific recommendations, this technical note begins with some basics on the excavation operating characteristics of various dredges and the factors that influence excavation accuracy. A discussion of excavation accuracy based on sediment types and location (sheltered versus exposed) is also provided. Finally, based on currently available data and Corps and contractor experiences, some recommendations for appropriate characterization depths are provided relative to different type of dredges in various site-specific conditions. As additional data are collected, these recommended characterization depths may be updated.

DREDGE EXCAVATION CHARACTERISTICS: There are inherent excavation inaccuracies in the dredging processes. No dredge excavates a perfectly flat bottom exactly on the required project grade. Excavation accuracy relates to closeness of the dredge's completed work to the required project and/or overdepth grade as determined by after-dredge hydrographic surveys. Dredge excavation accuracies vary as a function of the type of dredging equipment used (mechanical or hydraulic) and its respective interaction with site-specific physical conditions (tides, currents, waves), type and thickness of sediment or rock being dredged, channel design (water depth, side slopes, etc.) and level of dredge crew skill and effort. Error components introduced by the dredge's positioning system and the hydrographic surveying techniques and equipment used to measure bathymetry will also contribute to overall excavation accuracy.

Various factors influence the selection of dredging plant and its inherent excavation accuracy for a specific project. For those factors that most influence excavation accuracy and thus characterization depth, additional information is provided. These factors include:

- Physical characteristics of material to be dredged. Dredging of navigation projects falls into two basic categories, new work dredging and maintenance dredging. New work dredging occurs on new channels or navigation projects that are being deepened. Thus the material typically has not been dredged before, and is much more likely to be consolidated or cemented materials, or rock. The material is often more difficult to remove, requiring higher forces (sometimes blasting), and thus the bottom relief following dredging is generally greater than with maintenance dredging. Also, the material is generally more heterogeneous in new work dredging, which also increases the post-dredge bottom relief. Maintenance dredging material is in almost all cases recently

deposited, non-consolidated material, and thus is easier to dredge resulting in the post-dredging bottom being smoother (less relief) with less differences between the high and low points. The following terminology relating to different types of soil and rock are referenced from American Society for Testing and Materials (2005).

- Clay – fine-grained material or the fine-grained portion of soil that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air dried.
- Silt (inorganic silt, rock flour) – material passing the No. 200 (75-µm) US Standard sieve that is non-plastic or very slightly plastic and that exhibits little or no strength when air-dried.
- Sand - particles of rock that will pass the No. 4 (4.75-mm) sieve and be retained on the No. 200 (75-µm) US Standard sieve.
- Rock – natural solid mineral matter in large masses or fragments.
- Glacial till (till) – material deposited by glaciation, usually composed of a wide range of particle sizes, which has not been subjected to the sorting action of water.

Submarine blasting is required to remove material, usually rock, that cannot be excavated by dredging alone. Vertical holes are drilled into the rock, packed with explosives that when detonated, generate pressure in the form of a shock wave that shatters the rock into fragments. Factors that affect the amount of breakage include the rock's physical properties (strength, mass structure, and variability, etc.), hole (horizontal) spacing and depth, and type and size of explosive charges used. Holes must be drilled to a proper depth below the desired grade to allow the dredge to excavate to that grade, and the resultant rock fragments must be small enough in size to be handled by the dredge.

- Quantities and physical layout of materials to be dredged (i.e., varying types of stratified material).
- Channel design (water depth, side slopes, etc.)
- Location of both the dredging and placement sites and distance between them.
- Physical environment (i.e., waves, tides, currents) of and between the dredging and disposal placement areas. In open coastal locations, higher waves and currents decrease dredging accuracy.
- Contamination level of sediments.
- Method of placement.
- Production required.
- Type of dredges available.

Physical Environment Impacts on Hydrographic Surveying and Dredging Accuracy. Because hydrographic surveying is used to measure the depth to the bottom before and after dredging, the accuracy of the hydrographic survey is a critical component in determining characterization depth. In the relative calm of sheltered harbors, bays, and estuaries, typical hydrographic survey accuracies of +/- 0.5 ft are achievable for a majority of the soundings at a 95-percent statistical confidence level. As exposure to the elements increases, so can the motion of the hydrographic survey vessel, reducing the accuracy of the individual soundings. Additionally, the water surface's relationship to the dredge datum must be established and measured during times of surveying and dredging (USACE 2002). This is typically achieved by using a tide gage or Real Time Kinematic (RTK) methodology. Either selection requires accurate modeling to avoid height/time tide errors. For example, if the tide gage is a long distance from the dredging area, the water surface at the dredging site can be a different elevation from the tide gage, further reducing accuracy of the hydrographic survey.

The dredge often relies on the same methodology for determining the depth of the excavation head, therefore reductions in accuracy that impact the hydrographic surveying will also impact dredging accuracy. Increased wave heights also impact the dredge, reducing accuracy as the increased hull motion is transmitted to the excavation head. Hopper dredges, which are designed to work in the open ocean, have heave compensators to reduce wave impacts, but accuracy is reduced as wave heights increase.

DREDGE TYPES: General dredge classification is based on the method with which the dredge extracts the submerged sediment. The major types of dredges used in USACE navigation projects are mechanical and hydraulic dredges.

Mechanical Dredges. Most mechanical dredges scoop sediment into a bucket-shaped container and bring it to the surface where it is released into a placement area or transportation unit. These dredges usually consist of an excavating device (i.e., clamshell bucket, backhoe, or power shovel) mounted on the deck of a non-self-propelled barge. Some versions use conventional track or rubberwheel-mounted excavators (used on land) that are driven onto barges for temporary use, while others have the excavator's turntable (horizontal swivel point) directly mounted to the barge deck. In operation, the dredge holds its position by taking tension on anchors deployed around the barge, and/or by dropping spuds (vertically oriented, large-diameter steel pipe) into the bottom sediment. Once the dredge has excavated all the sediment it can reach to the required depth at one station, it is repositioned to a new location to begin digging again. This relocation can be accomplished in a variety of ways, i.e., an anchor/winch system, tug, movable spud system, or even by using the bucket itself as an anchor point.

Clamshell (Bucket) Dredge. A clamshell dredge lowers the opened clamshell bucket from the end of a crane boom into the sediment (Figure 2). After penetrating the sediment, the bucket jaws are closed in order to "grab" a load of sediment. The loaded bucket is hoisted to the surface and usually side dumped into a barge or sidecast to its placement site. The general clamshell dredge's horizontal excavation pattern is illustrated in Figure 3. Once an area is dredged within crane tip range, the dredge is repositioned and the process is started again.

The conventional clamshell is scalloped-shaped as illustrated in Figure 2, and when it excavates a "bite" from the bottom, it can create a "scalloped-shaped" pattern as illustrated in Figure 4.

Some bucket types are designed to excavate in a level cut as illustrated in Figure 5 to produce a flatter bottom, but there can be trade-offs in that these types of buckets can have less penetration capacity than the more conventional types into sediment, thereby reducing production efficiency. Figure 6 shows a multibeam after a dredge hydrographic survey that illustrates a typical clamshell (bucket) dredge excavation pattern. Various bucket configurations and weights with different digging characteristics are used to optimize production rates for site-specific conditions. Some bucket closing edges are smooth, while others have teeth to maximize the bucket's load. Except for the most cohesive consolidated sediments, coral, and rock, clamshell bucket dredges can excavate most types of material.

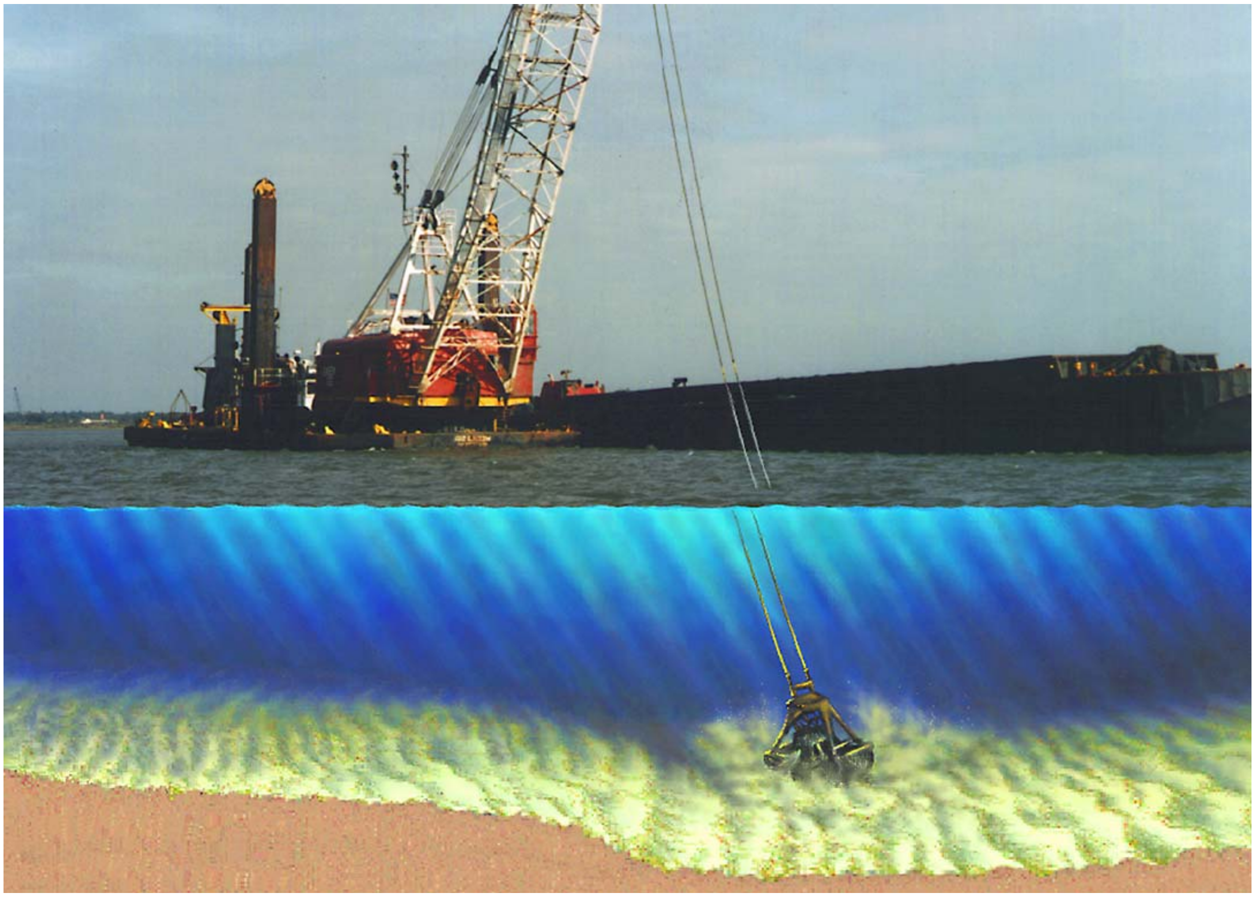

Figure 2. Clamshell (bucket) dredge.

Because the clamshell bucket is mounted on a flexible wire rope, its weight heavily influences the maximum digging force that can be applied to the sediment. Larger, heavier buckets are used to excavate more consolidated sediments. The bucket's penetration depth into the sediment is a function of its weight and the amount of momentum (dependant on its descent velocity) it has upon contacting the bottom. This interaction between bucket and sediment can impact this dredge type's excavation accuracy if the sediment is consolidated enough for the operator to rely excessively on the bucket's momentum to sufficiently penetrate the substrate. Due to the flexible wire rope connection between bucket and crane, this type of dredge's excavation accuracy can be less than the other mechanical dredge type, the backhoe, because the backhoe bucket is connected by rigid structural members. The presence of debris sufficient in size and composition

can also reduce excavation accuracy by preventing total closure of the bucket. Excessive waves and currents can, depending on the bucket size and weight, and the barge's positioning system (spuds or anchors), reduce excavation accuracy by causing the bucket to sway and/or deviate from its intended horizontal target.

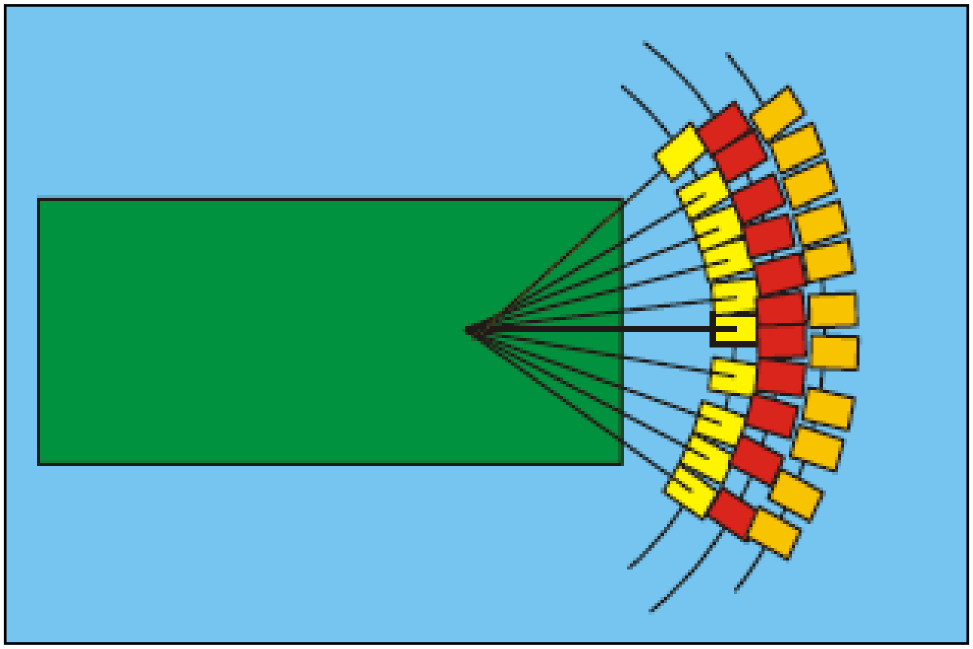

Figure 3. Clamshell dredge's general horizontal excavation pattern.

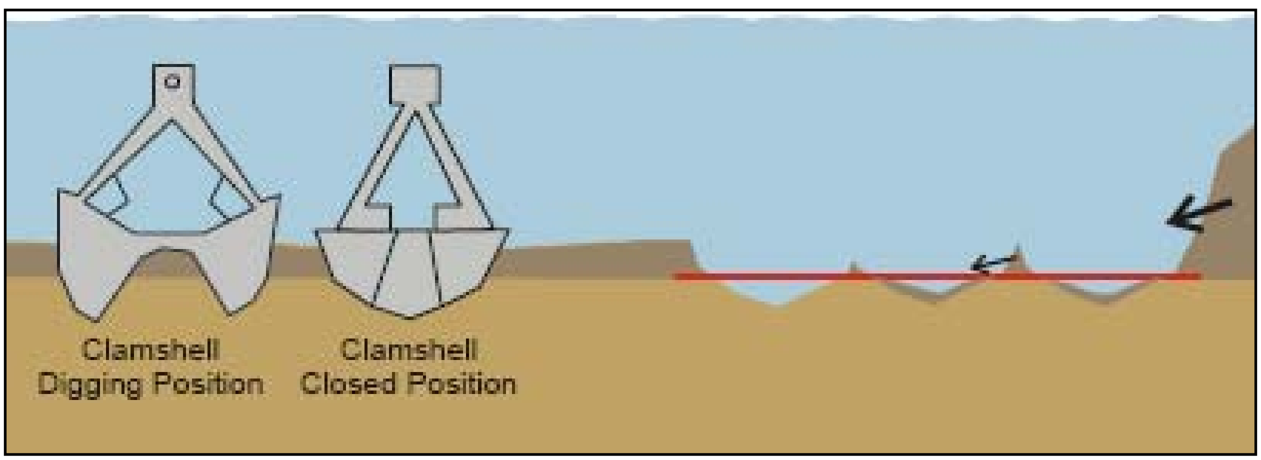

Figure 4. General conventional clamshell excavation profile.

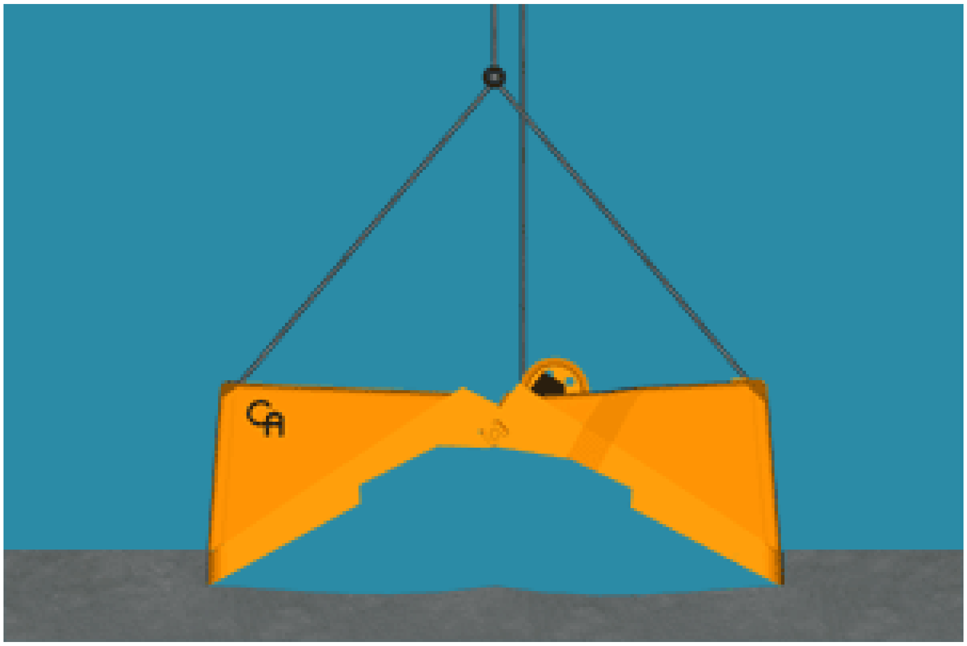

Figure 5. General level cut bucket excavation profile (Source: Cable Arm).

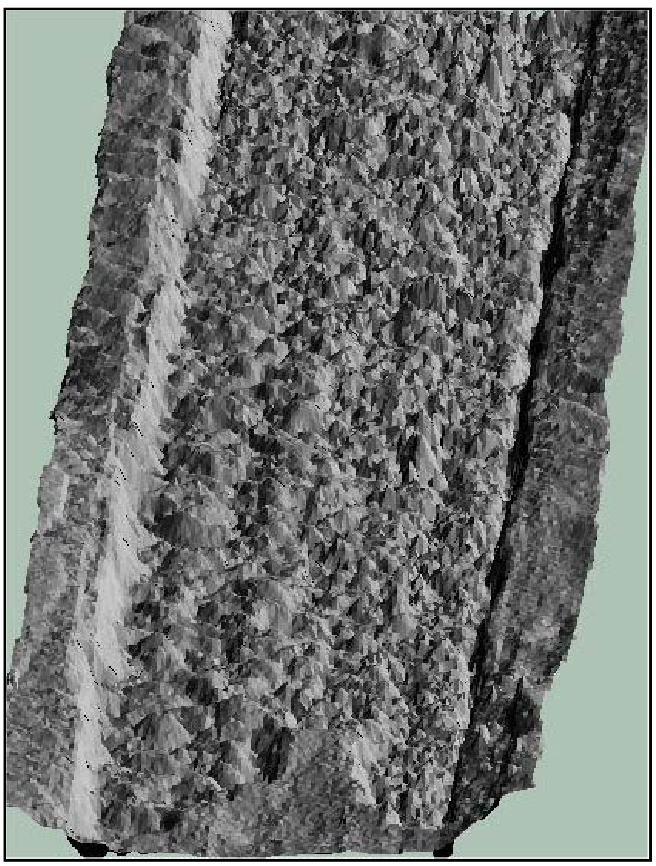

Figure 6. Clamshell (bucket) dredge excavation pattern (Courtesy of Great Lakes Dredge and Dock Dredging Company) surveyed by a multi-beam hydrographic surveying system.

Backhoe Dredges. Backhoe dredges are basically land excavators that have been modified for use on water. A mobile (tracked or wheel-mounted) backhoe excavator can be temporarily secured to a barge deck (like the clamshell dredge), or the more permanent versions have the excavator's turntable welded to the deck. The bucket is usually hydraulically activated on a structural member (boom/stick) configuration as shown in Figure 7. While working, the barge is usually held in place by spuds to provide reaction forces to the digging-induced forces. The bucket is filled with sediment as it penetrates down into the sediment and is pulled toward the operator by manipulating the structural members (boom/stick) and rolling back the bucket to retain the load (illustrated in Figure 8) while being transported to the surface.

Backhoe operational characteristics provide relatively high horizontal control and they can, like clamshell dredges, work relatively close around structures with a horizontal excavation pattern similar to that shown in Figure 3. The backhoe bucket's vertical excavation profile is similar to that of a clamshell and can produce a bottom pattern similar to Figure 4.

Figure 7. Backhoe Dredge (Dredge New York, courtesy of Great Lakes Dredge and Dock Company).

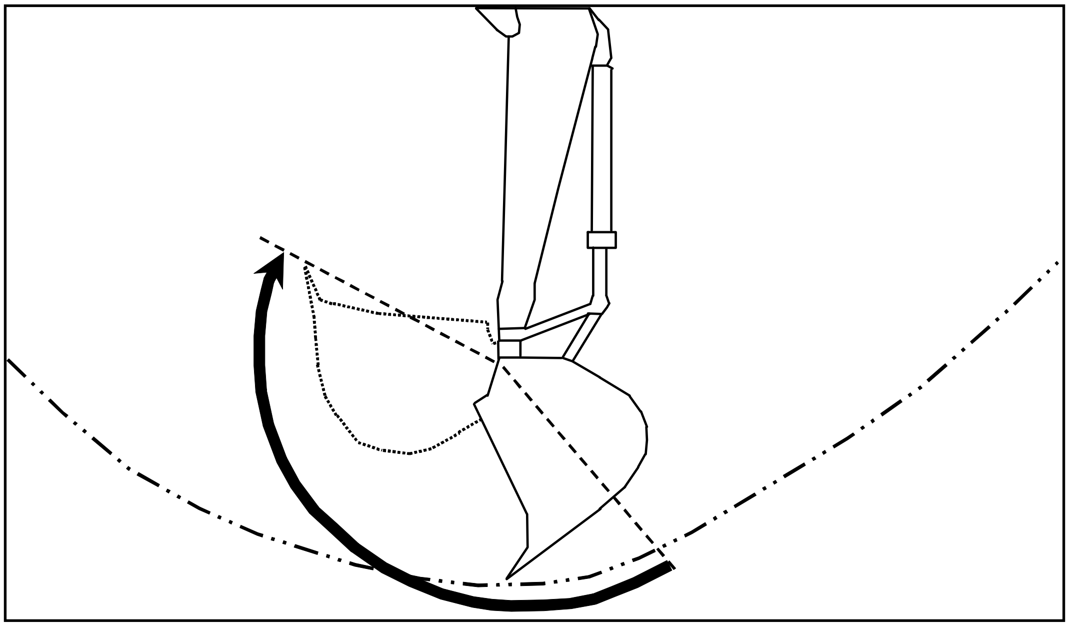

Figure 8. Backhoe bucket “rollback” to retain sediment load.

Hydraulic Dredges. Hydraulic dredges generally use a centrifugal pump to excavate the dredged material in the form of a slurry (water and sediment mixture). The most common types of hydraulic dredges used, hopper and pipeline, are classified by their respective means of transporting material to the disposal site.

Hopper Dredges. Hopper dredges (Figure 9) are self-propelled vessels that pump slurry into onboard hoppers for transportation to the disposal site. While excavating, the dredge uses centrifugal pumps to generate low head/high volume water flow rates into specially designed suction mouths, or dragheads, that slide along the bottom entraining sediments. Normal configuration, as shown in Figure 9, has two drag pipes, one on each side of the ship, with dragheads connected to the ends. These dragpipe/draghead assemblages are raised and lowered by cables. The draghead is moved (dragged) along the channel bottom as the vessel moves forward. In consolidated material i.e., sand, more of the dragpipe/draghead assembly weight is usually applied to the bottom (or less tension in the cables), as opposed to dredging an unconsolidated bottom, where, to maintain a required depth, the majority of the assembly’s weight may be cable-supported.

A hopper dredge will usually excavate material in a series of long cuts (an example of this type of dredge’s excavation pattern is illustrated by the after dredge multibeam hydrographic survey in Figure 10). Side bank dredging (i.e., dredging channel side slopes) can be difficult with this type of dredge because the draghead may tend to slide down the bank and under the ship, thereby decreasing its excavation accuracy. An advantage of hopper dredges is that they can be used in relatively high seas (up to 12-ft swells), but, over some threshold value, as the wave height increases, excavation accuracy decreases. This type of dredge’s production (and respective excavation accuracy) decreases in the more cohesive and consolidated sediments. Hopper dredges cannot work in competent rock.

Figure 9. Hopper dredge.

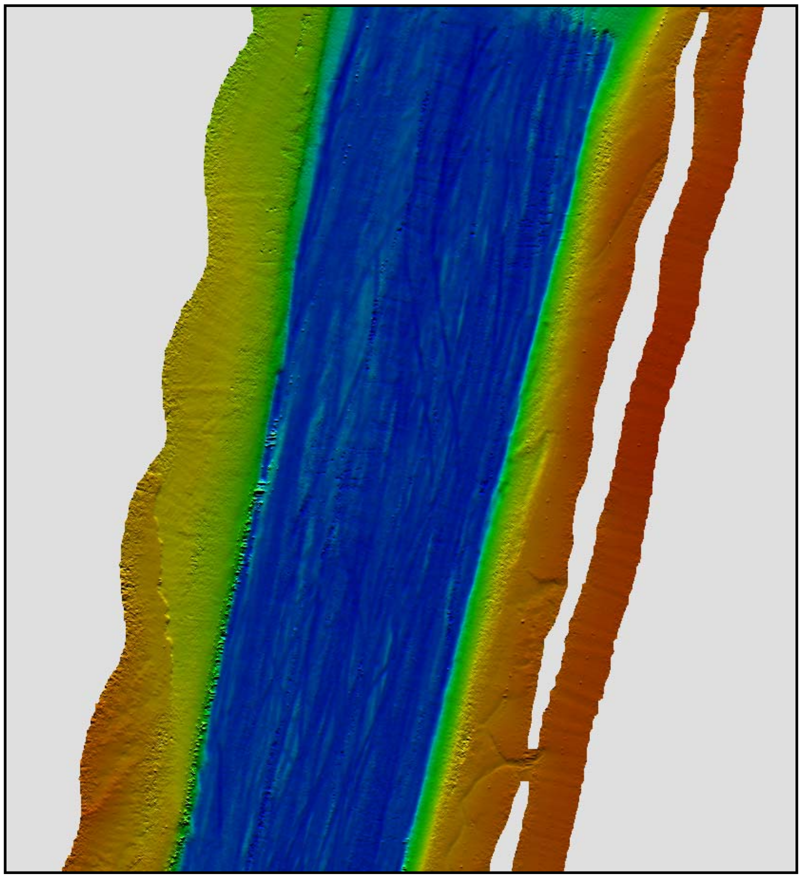

Figure 10. Hopper dredge excavation pattern surveyed by a multi-beam hydrographic surveying system.

Hydraulic Cutterhead Pipeline Dredge. The hydraulic cutterhead pipeline dredge also uses a centrifugal pump to entrain the sediment into a slurry, but instead of using a hopper for transporting dredged material to the placement site, it conveys the material through a pipeline connected to the pump discharge. This type of dredge is typically comprised of a hull, main pump and engine, ladder, suction pipe, cutterhead, spuds, and hoisting and hauling equipment (Figure 11). During operation, a floating (or submerged) discharge pipeline transports the slurry to the disposal site. Most hydraulic pipeline dredges are barge-mounted without propulsion and require dredge tenders for mobilization to the dredge site.

The conventional method of advancement into the face is controlled primarily by a system of winding gear, anchors, and spuds. When positioned on station, the port and starboard swing anchors, connected to the winches by wire rope, are set out a distance from the bow by derrick barges. The dredge is usually equipped with two stern spuds that can be raised or lowered (one at a time) into the bottom to function as pivot points.

In production, one of the spuds is set in the bottom as a pivot point and the leverman lowers the cutterhead into the sediment and moves it across the channel in a circular arc by taking in one swing anchor cable while slacking off the other (this horizontal excavation pattern is illustrated in Figure 12 and a general vertical profile in Figure 13). The dredge advances, or steps, forward in the channel by alternating spud sets (i.e. swing to starboard on the starboard spud, then swing to port on the port spud). This sequence of swinging and spud setting (stabbing) in the channel has many variations, including traveling spud carriages that physically push the dredge forward, but the advancement technique is fundamentally the same for the majority of hydraulic pipeline dredges.

The bottom material's interaction (or behavior) with the cutterhead/suction mouth assembly determines the relative vertical (cutterhead) position in the substrate required to achieve grade. The cutterhead is placed by the dredge operator at a desired depth based on this material behavior, usually by tracking the bottom invert of the suction pipe (mouthpiece) where it is attached to the cutterhead. The cutterhead itself extends beyond and below the bottom invert of the suction pipe a distance that is dependent on (a) the geometry of the cutter, and (b) the angle of inclination of the dredge ladder. Dredging will be conducted at a given digging depth, then daily after dredge hydrographic surveys are generally used to determine if the desired grade is being achieved. The digging depth is adjusted frequently during the dredging project using this process, depending upon the type of material being dredged as well as the other variables involved in a dredging operation.

The vertical profile in Figure 13 illustrates the fact that not all material encountered by the cutterhead is entrained into the suction pipe; some is left behind as spillage. Note: spillage also occurs with hopper and mechanical dredges, though to a somewhat lesser degree. Dredging contractors pay attention to the amount of material left behind (using an after-dredge hydrographic survey) and adjust their operations accordingly. For example, if required project grade is not being reached, the cutterhead will be lowered for a day, then a survey is conducted to see the result. In contrast, if contractors are consistently below paid overdepth, they will adjust upwards. Figure 14 shows a multibeam after-dredge hydrographic survey that illustrates a typical cutterhead dredge excavation pattern.

Based on empirical evidence from extensive dredging experiences, the bottom invert of the suction pipe is a very good approximation of the desired grade. This does not necessarily mean that is precisely the elevation actually achieved, as a number of factors affect the final bottom grade relative to the bottom invert of the suction pipe. These factors include (a) spillage behind the mouthpiece by the cutter, (b) material sloughing off the cut face before or after the cutter has passed, (c) speed at which the cutter is moving, and (d) the nature of the material being excavated.

Like the other dredges, the cutterhead's excavation accuracy depends on its respective interaction with site-specific physical conditions (tides, currents, waves), type and thickness of sediment or rock being dredged, channel design (water depth, side slopes, etc.), and level of dredge crew skill and effort.

Figure 11. Hydraulic cutterhead pipeline dredge.

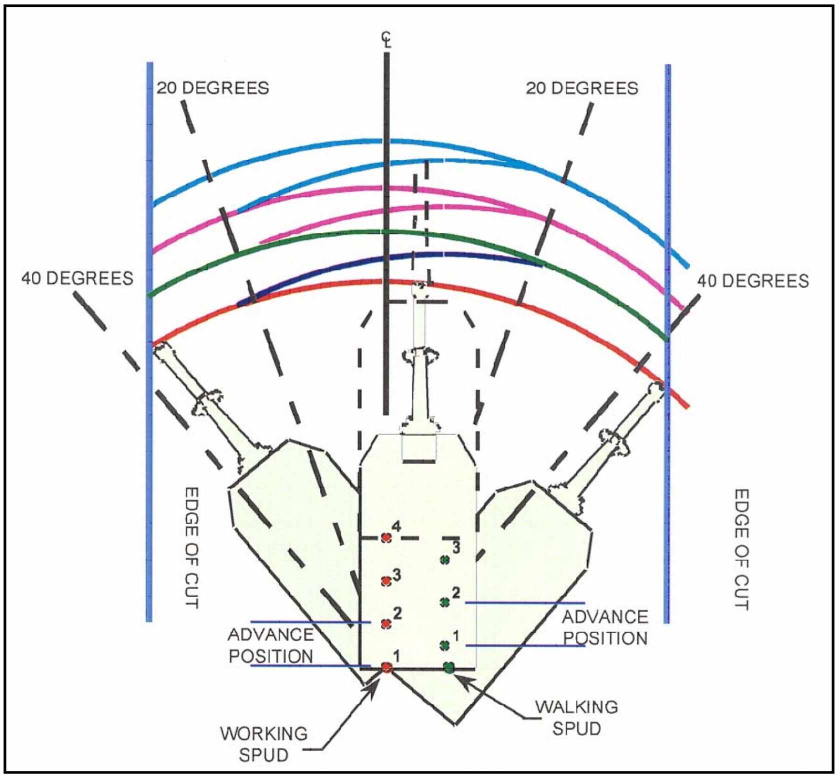

Figure 12. Cutterhead dredge's general horizontal excavation pattern.

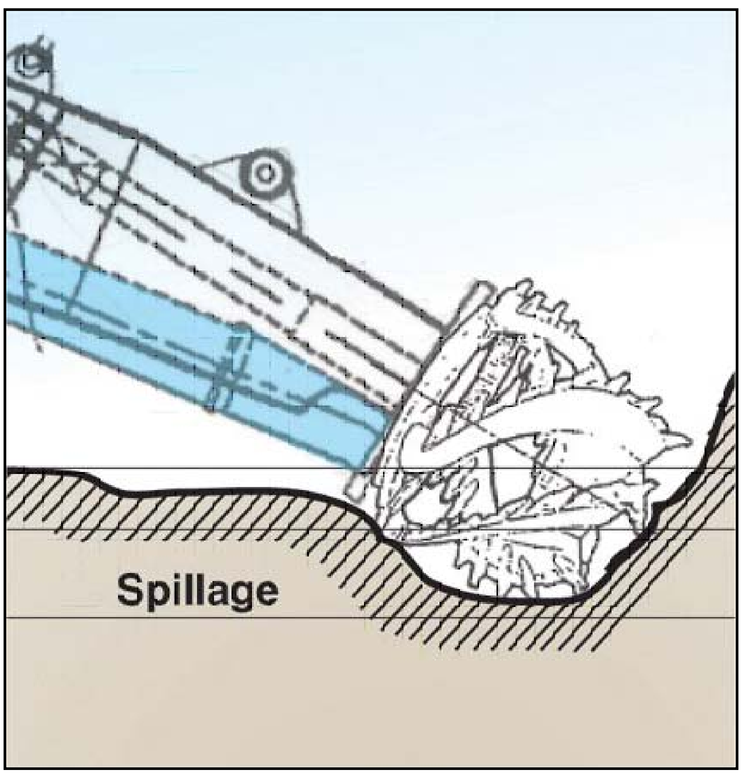

Figure 13. General vertical excavation profile of a cutterhead dredge.

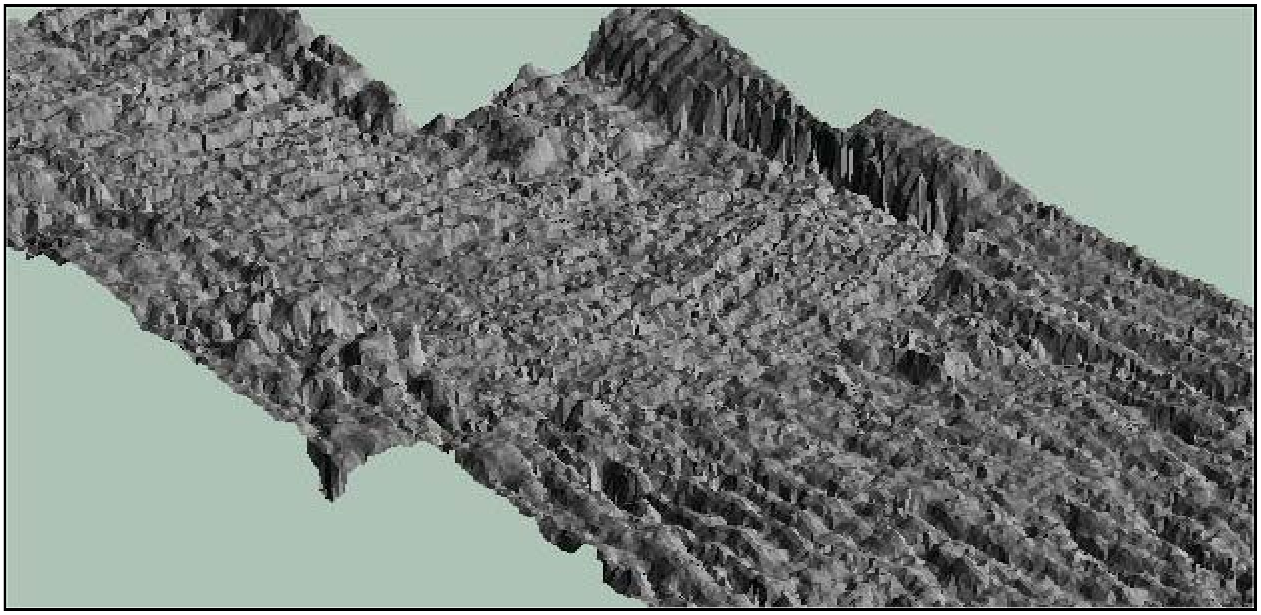

Figure 14. Cutterhead dredge excavation pattern (Courtesy of Great Lakes Dredge and Dock Dredging Company) surveyed by a multi-beam hydrographic surveying system.

OVERDEPTH DREDGING: This section presents some results from a recent analysis (Tavolaro and Weinberg 2006) related to dredge excavation accuracy based on 11 dredging projects consisting of different types of dredges (hopper, backhoe, and clamshell) excavating different types of material (till, rock, clay, sand, and silt), in sheltered and exposed locations. The following discussion focuses on overdepth dredging on deepening (new work) and maintenance projects.

Tavolaro and Weinberg (2006) noted that ensuring adequate sediment characterization of the overdepth dredging does not necessarily imply that additional testing needs to be done. In most cases harbor deepening projects are dredging pre-industrial ancient sediments or rock with depth, which are usually not contaminated. Whether or not to test this sediment depends on the project specifics, and whether there is reason to believe the sediments might be contaminated. The goal is to have enough environmental information to adequately and appropriately characterize the sediments with depth to ensure that environmental documentation, such as National Environmental Policy Act (NEPA) analyses, can take the required "hard look" at potential environmental impacts and come to meaningful and complete conclusions. The level of information necessary to achieve this goal will vary from project to project, but the evaluations must take into account the overdepth dredging or they will be incomplete.

Deepening Dredging Projects. The authors concluded that for deepening projects, it appears that the degree of overdepth dredging is fairly predictable and consistent, regardless of whether a clamshell or backhoe dredge was used. Because of the relatively hard nature of the dredged material (rock, till, and clay) it appears that the dredge operator takes into account that dredging is less precise than in softer materials. Dredge buckets designed to dig hard materials such as rock and till have large-toothed lips, which are geared to penetrate and rip up large chunks of the bottom. To increase efficiency and minimize the possibility of having to re-dredge areas that have not achieved the required project grade, dredge operators set the excavation depth to 1–2 ft below the maximum pay depth.

Harbor (Sheltered) Maintenance Dredging Projects. For harbor maintenance dredging projects using a clamshell dredge it also appears that the degree of overdepth dredging is fairly predictable and consistent. Because of the relatively soft nature of the fine-grained silts being dredged it does not appear that dredge operators need as much depth to account for dredging variability. It appears that setting the excavation depth to the maximum pay depth is adequate to ensure that operators efficiently achieve the required grade. The soft nature of the dredged material appears to minimize the amount of non-pay overdepth dredging and in some cases may actually facilitate moving the dredged material around on the bottom so that there is a net "gain "of non-pay overdepth dredged material as areas within the dredging prism (that were already deeper than the dredging prism) are filled.

Tavolaro and Weinberg (2006) concluded that the implications for project design include the fact that engineers need not factor in more than 2 ft of allowable overdepth in their designs for mechanical maintenance dredging in soft materials. In this case, existing Corps of Engineers regulations and technical guidance do not seem to differentiate between project design for deepening projects and maintenance projects, and appear to be more conservative in approach than what is needed for maintenance dredging. The guidance appears to be most appropriate for deepening projects. The environmental implications are that sediment characterization may not need to consider more than the 1–2 ft of allowable overdepth already contained in most project designs. However it is still important to appropriately characterize all overdepth quantities, pay and non-pay, in required environmental reviews in order to fully comply with existing laws and regulations. Similar considerations outlined above for deepening projects apply here as well. Also, environmental reviews must recognize that some degree of sediment re-contouring of the bottom may occur due to the soft nature of the material and the action of the clamshell. The degree to which this occurs will vary based on project specifics and should be evaluated on a case-by-case basis.

Coastal (Exposed) Maintenance Dredging Projects. For coastal maintenance dredging projects, overdepth dredging appears to be the least predictable of the cases observed due to the dynamic nature of the dredging environment and the nature of hopper dredging. The authors concluded that because hopper dredging in easily removable sediment, such as sand, is more accurate than mechanical dredging, dredgers can target the required depth as their goal. However, due to the dynamic nature of coastal inlets there is evidence that channel infilling may be taking place as dredging is occurring, based on the secondary modality seen in the authors' statistical analyses. This could cause a net gain in non-pay material to be observed, but this would be due to natural processes, not to the action of the dredge, as appears to be the case with harbor maintenance projects.

The implications for project design are similar to those for harbor maintenance dredging, i.e. that engineers need not factor in more than 2 ft of allowable overdepth in their designs for hopper dredging in sand. As for harbor maintenance dredging projects, Corps regulations and technical guidance on overdepth considerations may be more conservative than is necessary for these types of coastal maintenance projects. The environmental implications are the same as for harbor maintenance projects, i.e. consideration of the 1–2 ft of allowable overdepth already contained in most project designs appear to be adequate, and that any additional non-pay overdepth quantity will not be significant. Environmental reviews should recognize that channel infilling may occur during the dredging process, and that since sand does not generally accumulate chemical

contaminants due to their chemically inert nature, adequate sediment characterization may merely involve confirming that the sediment with depth is truly sand.

Tavolaro and Weinberg (2006) noted that the conclusions reached as a result of this study were based on a fairly limited number of cases. As mentioned earlier, there are many variables that could affect the degree of overdepth dredging and this technical note could not possibly take all those factors into account. Tavolaro and Weinberg suggested that more detailed analyses that account for each variable would provide greater insight as to their relative influence on overdepth dredging. However, even with the limited number of examples covered in this technical note, it is interesting to note that certain patterns can be discerned and these results do lead to reasonable conclusions about the nature of overdepth dredging.

CHARACTERIZATION DEPTH RECOMMENDATIONS: To meet environmental compliance requirements, sediments must be characterized to the reasonably predicted maximum depth and horizontal extent that could be dredged for the reasons described earlier. This is neither an exhaustive nor all-inclusive exercise. It must be understood that the material characterized will be an approximation.

The values on the following pages are recommended characterization depths understanding that on any given dredging project the depths characterized may vary by a margin of error of less than a foot or more than several feet. For example, when dredging in rock, large “chunks” of dredged material may be excavated as a single unit by a mechanical dredge. Those chunks may result from irregular fracturing of large rock formations by forces applied by the dredge, or result from fractures from the blasting process. In certain projects, i.e., those involving box cuts where the width of cut is sufficient to allow slope material to slough off (or cave) to the natural underwater repose of that material without encroaching the desired channel dimensions, an appropriate characterization depth (and resultant horizontal distance) from the channel toe and side slope must be selected such that this material can be characterized and evaluated with regard to its suitability for the proposed placement method. The additional width beyond the channel toe that’s added to account for box cutting is project- and dredge-specific, and thus is best made by experienced District staff (possibly in consultation with the dredging contractors). In spite of every effort to provide specific “numbers” that would be dredged as a matter of overdepth, dredging and measuring bottom profiles following dredging are not exact sciences.

Suggestions for Using the Recommended Characterization Depths. The following section is the critical part of this technical note. It includes a flowchart (Figure 15) and accompanying narrative descriptions that provide minimum recommended depths of characterization for various site-specific conditions for the three basic types of dredges used in Corps navigation dredging (mechanical dredges, hydraulic cutterhead dredges, and hopper dredges) operating in either new work or maintenance dredging projects. The user should examine the flowchart to first determine the class of dredging (maintenance or new work), then, based on the location of the dredging, determine if the dredging will be done in exposed open water or a sheltered harbor location. The user should then review the geotechnical information on the type of sediments to be removed, and select the respective scenario designation (NOC3, MSC2, etc.) from the flowchart. With this code, a user can refer to the appropriate narrative for characterization depth recommendations applicable to their respective projects.

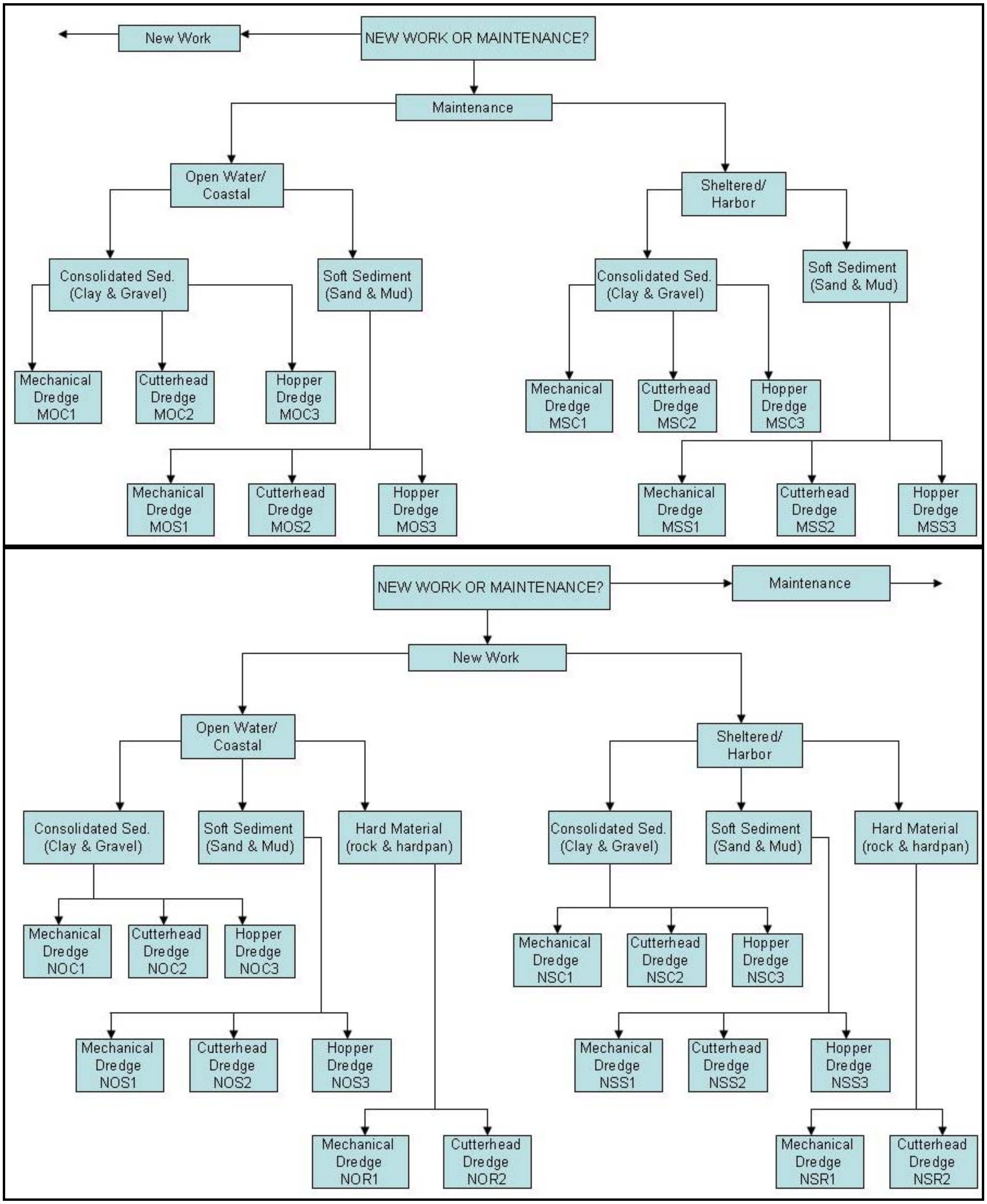

Figure 15. Dredging scenario flowchart for determining characterization depth

In those scenarios where multiple dredge types are appropriate, the user should select the greatest recommended characterization depth. For example, for a sheltered harbor maintenance dredging project with soft sediments, a mechanical dredge (MSS1), hydraulic cutterhead dredge (MSS2), or hopper dredge (MSS3) are all suitable dredge plants. The recommended minimum characterization depths below the required depth are 6 ft for the mechanical dredge, 7 ft for the cutterhead dredge, and 3 ft for the hopper dredge. If past dredging indicates the potential for use of any of the three dredge types, then the recommended characterization depth would be the maximum, 7 ft for the hydraulic cutterhead dredge. However, the distance to the placement site or other factors may eliminate one or more of the dredge types, in which case the maximum recommended characterization depth of the remaining dredge type(s) should be used.

When making a decision on characterization depth, consulting with the project's operations managers, hydrographic surveyors, and competent dredging contractors is highly recommended. The operations managers can provide information based on their experiences on the subject project or similar projects. The hydrographic surveyors can provide estimates of surveying accuracy for the project, and note if extreme conditions that reduce accuracy are likely to occur. It may also be worthwhile to consult with knowledgeable dredging contractors on what they have experienced or what they would expect the dredging accuracy to be in those site-specific conditions. As illustrated by Tavolaro and Weinberg (2006), review of historical before and after dredging surveys of the project in question, or similar projects, is an excellent source of information on how much below the required depth a given dredge type is likely to dig.

OVERDEPTH DREDGING SCENARIOS

Maintenance Dredging Scenarios:

- **MOC1**
  Definition: Maintenance dredging of consolidated dredged materials with mechanical equipment in exposed open-water conditions.
  Considerations: Mechanical equipment is not normally used because of significant down time due to rough seas. Consolidated materials tend to excavate unevenly, due to large "chunks" being ripped up.
  Expectations: Expect a high degree of inaccuracy in dredging depth, and a very uneven bottom when done. The dredge operator will dredge at least 2 ft below maximum pay depth (with an allowable overdepth of 2 ft) to achieve required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 4 ft below required depth to achieve grade.
  Recommendations: Dredged material should be characterized to a depth of not less than 6 ft below required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft (or perhaps more in extreme situations) should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **MOC2**
  Definition: Maintenance dredging of consolidated dredged materials with a hydraulic cutterhead in exposed open-water conditions.
  Considerations: Cutterhead dredging equipment tends to disturb the bottom sediments

several feet deeper than the target depth, as noted in the description of cutterhead dredges earlier in the document. Larger dredges tend to have larger cutterheads and will disturb the sediments to a greater depth. Consolidated materials tend to excavate unevenly, due to large "chunks" being ripped up.
Expectations: Expect a moderate degree of accuracy in dredging depth, with some gouges in the bottom when done. The dredge operator will dredge at least 3 ft below maximum pay depth (with an allowable overdepth of 2 ft) to achieve required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 5 ft below required depth to achieve grade.
Recommendations: Dredged material should be characterized to a depth of not less than 7 ft below required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft (or perhaps more in extreme situations) should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **MOC3**
  Definition: Maintenance dredging of consolidated dredged materials with a hopper dredge in exposed open-water conditions.
  Considerations: Hopper dredges are not well suited to dig consolidated materials due to a lack of mechanical power at the draghead.
  Expectations: Expect that the hopper dredge will have difficulty achieving grade. Overdepth dredging should not be an issue under this scenario.
  Recommendations: Reconsider using a hopper dredge for digging consolidated materials.

- **MOS1**
  Definition: Maintenance dredging of soft dredged materials with mechanical equipment in exposed open-water conditions.
  Considerations: Mechanical equipment is not normally used because of significant down time due to rough seas. Soft sediments also tend to move around and shoals shift in some open-water situations.
  Expectations: Expect a high degree of inaccuracy in dredging depth, and a very uneven bottom when done. The dredge operator will dredge at least 2 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 4 ft below the required depth to achieve grade. However, if the environment is conducive to shifting shoals, expect some infilling to occur in areas already dredged.
  Recommendations: Dredged material should be characterized to a depth of not less than 6 ft below required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft (or perhaps more in extreme situations) should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **MOS2**
  Definition: Maintenance dredging of soft dredged materials with a hydraulic cutterhead in exposed open-water conditions.
  Considerations: Cutterhead dredging equipment tends to disturb the bottom sediments several feet deeper than the target depth, as noted in the description of cutterhead dredges

earlier in the document. Larger dredges tend to have larger cutterheads and will disturb the sediments to a greater depth. Soft sediments also tend to move around and shoals shift in some open-water situations.
Expectations: Expect a moderate degree of accuracy in dredging depth. The dredge operator will dredge at least 3 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 5 ft below required depth to achieve grade. However, if the environment is conducive to shifting shoals, expect some infilling to occur in areas already dredged.
Recommendations: Dredged material should be characterized to a depth of not less than 7 ft below required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft (or perhaps more in extreme situations) should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **MOS3**
Definition: Maintenance dredging of soft dredged materials with a hopper dredge in exposed open-water conditions.
Considerations: Hopper dredges tend to disturb the bottom sediments approximately 1 ft deeper than the target depth. Soft sediments also tend to move around and shoals shift in some open-water situations.
Expectations: Expect a good degree of accuracy in dredging depth, with small ridges left behind between drag arm passes. The dredge operator will dredge approximately 1 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will still dredge approximately 1 ft below required depth to achieve grade. However, if the environment is conducive to shifting shoals, expect some infilling to occur in areas already dredged. In these situations, the dredge operator may still dredge approximately 2 ft below maximum pay depth. Also, due to heave and swell, some deeper gouges may occur, up to 2 to 3 ft deeper.
Recommendations: Dredged material should be characterized to a depth of not less than 5 ft below maximum pay depth if 2 ft of allowable overdepth is part of the project design. If less than 2 ft of allowable overdepth is included, dredged material should be characterized approximately 4 ft below required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft (or perhaps more in extreme situations) should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **MSC1**
Definition: Maintenance dredging of consolidated dredged materials with mechanical equipment in sheltered/harbor conditions.
Considerations: Mechanical equipment is well suited to dredge consolidated material. Consolidated materials tend to excavate unevenly, due to large “chunks” being ripped up.
Expectations: Expect a high degree of inaccuracy in dredging depth, and a very uneven bottom when done. The dredge operator will dredge at least 2 ft below maximum pay depth (with an allowable overdepth of 2 ft) to achieve required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 4 ft below required depth to

achieve grade.
Recommendations: Dredged material should be characterized to a depth of not less than 6 ft below required depth.

- **MSC2**
  Definition: Maintenance dredging of consolidated dredged materials with a hydraulic cutterhead in sheltered/harbor conditions.
  Considerations: The cutterhead tends to disturb the bottom sediments several feet deeper than the target depth, as noted in the description of cutterhead dredges earlier in the document. Larger dredges tend to have larger cutterheads and will disturb the sediments to a greater depth. Consolidated materials tend to excavate unevenly, due to large “chunks” being ripped up.
  Expectations: Expect a moderate degree of accuracy in dredging depth, with some gouges in the bottom when done. The dredge operator will dredge at least 3 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 5 ft below required depth to achieve grade.
  Recommendations: Dredged material should be characterized to a depth of not less than 7 ft below required depth.

- **MSC3**
  Definition: Maintenance dredging of consolidated dredged materials with a hopper dredge in sheltered/harbor conditions.
  Considerations: Hopper dredges are not well suited to dig consolidated materials due to a lack of mechanical power at the draghead.
  Expectations: Expect that the hopper dredge will have difficulty achieving grade. Overdepth dredging should not be an issue under this scenario.
  Recommendations: Reconsider using a hopper dredge for digging consolidated materials.

- **MSS1**
  Definition: Maintenance dredging of soft dredged materials with mechanical equipment in sheltered/harbor conditions.
  Considerations: Mechanical equipment is especially well suited for this work where there is limited maneuverability or dredging close to structures is required.
  Expectations: Expect a fair degree of accuracy in dredging depth, and a fairly smooth bottom when done, partly due to “smoothing” of the bottom with the dredge bucket. The dredge operator will disturb at least 2 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will disturb at least 4 ft below required depth to achieve grade.
  Recommendations: Dredged material should be characterized to a depth of not less than 6 ft below required depth if looking to characterize “disturbed depth.”

- **MSS2**
  Definition: Maintenance dredging of soft dredged materials with a hydraulic cutterhead in sheltered/harbor conditions.
  Considerations: The cutterhead tends to disturb the bottom sediments several feet deeper than the target depth, as noted in the description of cutterhead dredges earlier in the

document. Larger dredges tend to have larger cutterheads and will disturb the sediments to a greater depth. Soft sediments also tend to move around due to "plowing" of the bottom with the cutterhead.
Expectations: Expect a fair degree of accuracy in dredging depth. The dredge operator will disturb at least 3 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will disturb at least 5 ft below required depth to achieve grade.
Recommendations: Dredged material should be characterized to a depth of not less than 7 ft below required depth if looking to characterize "disturbed depth."

- **MSS3**
  Definition: Maintenance dredging of soft dredged materials with a hopper dredge in sheltered/harbor conditions.
  Considerations: Hopper dredges tend to disturb the bottom sediments approximately 1 ft deeper than the target depth. Soft sediments also tend to move around due to "plowing" of the bottom by the draghead, but to a lesser degree than cutterhead dredges.
  Expectations: Expect a good degree of accuracy in dredging depth, with small ridges left behind between dragarm passes. The dredge operator will dredge approximately 1 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will still dredge approximately 1 ft below required depth to achieve grade.
  Recommendations: Dredged material should be characterized to a depth of not less than 1 ft below maximum pay depth if 2 ft of allowable overdepth is part of project design. If less than 2 ft of allowable overdepth is included, dredged material should be characterized not less than 3 ft below required depth.

New Work Dredging Scenarios:

- **NOC1**
  Definition: New work dredging of consolidated dredged materials with mechanical equipment in exposed open-water conditions.
  Considerations: Mechanical equipment is not normally used because of significant down time due to rough seas. Consolidated materials tend to excavate unevenly, due to large "chunks" being ripped up.
  Expectations: Expect a high degree of inaccuracy in dredging depth, and a very uneven bottom when done. The dredge operator will dredge at least 2 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 4 ft below required depth to achieve grade.
  Recommendations: Dredged material should be characterized to a depth of not less than 6 ft below required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft (or perhaps more in extreme situations) should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **NOC2**
  Definition: New work dredging of consolidated dredged materials with a hydraulic cutterhead in exposed open-water conditions.
  Considerations: Cutterhead dredging equipment tends to disturb the bottom sediments several feet deeper than the target depth, as noted in the description of cutterhead dredges earlier in the document. Larger dredges tend to have larger cutterheads and will disturb the sediments to a greater depth. Consolidated materials tend to excavate unevenly, due to large "chunks" being ripped up.
  Expectations: Expect a moderate degree of accuracy in dredging depth, with some gouges in the bottom when done. The dredge operator will dredge at least 3 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 5 ft below required depth to achieve grade.
  Recommendations: Dredged material should be characterized to a depth of not less than 7 ft below required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft (or perhaps more in extreme situations) should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **NOC3**
  Definition: New work dredging of consolidated dredged materials with a hopper dredge in exposed open-water conditions.
  Considerations: Hopper dredges are not well suited to dig consolidated materials due to a lack of mechanical power at the draghead.
  Expectations: Expect that the hopper dredge will have difficulty achieving grade. Overdepth dredging should not be an issue under this scenario.
  Recommendations: Reconsider using a hopper dredge for digging consolidated materials.

- **NOS1**
  Definition: New work dredging of soft dredged materials with mechanical equipment in exposed open-water conditions.
  Considerations: Mechanical equipment is not normally used because of significant down time due to rough seas. Soft sediments also tend to move around and shoals shift in some open-water situations.
  Expectations: Expect a high degree of inaccuracy in dredging depth, and a very uneven bottom when done. The dredge operator will dredge at least 2 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 4 ft below required depth to achieve grade. However, if the environment is conducive to shifting shoals, expect some infilling to occur in areas already dredged.
  Recommendations: Dredged material should be characterized to a depth of not less than 6 ft below required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft (or perhaps more in extreme situations) should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **NOS2**
  Definition: New work dredging of soft dredged materials with a hydraulic cutterhead in exposed open-water conditions.
  Considerations: Cutterhead dredging equipment tends to disturb the bottom sediments approximately 3 ft deeper than the target depth. Soft sediments also tend to move around and shoals shift in some open-water situations.
  Expectations: Expect a moderate degree of accuracy in dredging depth. The dredge operator will dredge at least 3 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 5 ft below required depth to achieve grade. However, if the environment is conducive to shifting shoals, expect some infilling to occur in areas already dredged.
  Recommendations: Dredged material should be characterized to a depth of not less than 7 ft below required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft (or perhaps more in extreme situations) should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **NOS3**
  Definition: New work dredging of soft dredged materials with a hopper dredge in exposed open-water conditions.
  Considerations: Hopper dredges tend to disturb the bottom sediments approximately 1 ft deeper than the target depth. Soft sediments also tend to move around and shoals shift in some open-water situations.
  Expectations: Expect a good degree of accuracy in dredging depth, with small ridges left behind between drag arm passes. The dredge operator will dredge approximately 1 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will still dredge approximately 1 ft below required depth to achieve grade. However, if the environment is conducive to shifting shoals, expect some infilling to occur in areas already dredged. In these situations, the dredge operator may still dredge approximately 2 ft below maximum pay depth. Also, due to heave and swell, some deeper gouges, up to 2 to 3 ft deeper, may occur.
  Recommendations: Dredged material should be characterized to a depth of not less than 5 ft below maximum pay depth if 2 ft of allowable overdepth is part of the project design. If less than 2 ft of allowable overdepth is included, dredged material should be characterized not less than 4 ft below required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **NOR1**
  Definition: New work dredging of rock or hardpan with a mechanical dredge in exposed open-water conditions.
  Considerations: Mechanical equipment is well suited to dredge rock or hardpan, but open-water conditions will lower production rates due to significant down time. Rock and hardpan tend to excavate unevenly, due to large “chunks” being ripped up. If blasting is required prior

to dredging, expect the depth of disturbance to be much greater than dredging depth.
Expectations: Expect a high degree of inaccuracy in dredging depth, and a very uneven bottom when done. The dredge operator will dredge at least 2 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 4 ft below required depth to achieve grade.
Recommendations: Once bedrock or hardpan is reached, one should utilize geologic descriptions of the lithology to characterize the dredged material. In any event, one should ensure that the dredged material is characterized to a depth of not less than 6 ft below the required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft should be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **NOR2**
  Definition: New work dredging of rock or hardpan with a hydraulic cutterhead dredge in exposed open-water conditions.
  Considerations: For certain types of rock, hydraulic cutterhead dredges are adequately suited to dredge rock or hardpan. Rock and hardpan tend to excavate unevenly, due to large "chunks" being ripped up, but cutterhead tends to create smaller gouges than mechanical equipment. If blasting is required prior to dredging, expect the depth of disturbance to be much greater than the dredging depth.
  Expectations: Expect a high degree of inaccuracy in dredging depth, and a somewhat uneven bottom when done. The dredge operator will dredge at least 3 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 5 ft below required depth to achieve grade.
  Recommendations: Once bedrock or hardpan is reached, one should utilize geologic descriptions of the lithology to characterize the dredged material. In any event, one should ensure that the dredged material is characterized to a depth of not less than 7 ft below the required depth. Depending on the severity of conditions found in open water, an additional 1 to 3 ft (or perhaps more in extreme situations) could be added to the recommended characterization depth. See the earlier description of the impacts of severe conditions found in open water on surveying inaccuracies and on the dredge and operator.

- **NSC1**
  Definition: New work dredging of consolidated dredged materials with mechanical equipment in sheltered/harbor conditions.
  Considerations: Mechanical equipment is well suited to dredge consolidated material. Consolidated materials tend to excavate unevenly, due to large "chunks" being ripped up.
  Expectations: Expect a high degree of inaccuracy in dredging depth, and a very uneven bottom when done. The dredge operator will dredge at least 2 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 4 ft below required depth to achieve grade.
  Recommendations: Dredged material should be characterized to a depth of not less than 6 ft below required depth.

- **NSC2**
  Definition: New work dredging of consolidated dredged materials with a hydraulic cutterhead in sheltered/harbor conditions.
  Considerations: The cutterhead tends to disturb the bottom sediments several feet deeper than the target depth, as noted in the description of cutterhead dredges earlier in the document. Larger dredges tend to have larger cutterheads and will disturb the sediments to a greater depth. Consolidated materials tend to excavate unevenly, due to large “chunks” being ripped up.
  Expectations: Expect a moderate degree of accuracy in dredging depth, with some gouges in the bottom when done. The dredge operator will dredge at least 3 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 5 ft below required depth to achieve grade.
  Recommendations: Dredged material should be characterized to a depth of not less than 7 ft below required depth.

- **NSC3**
  Definition: New work dredging of consolidated dredged materials with a hopper dredge in sheltered/harbor conditions.
  Considerations: Hopper dredges are not well suited to dig consolidated materials due to a lack of mechanical power at the draghead.
  Expectations: Expect that the hopper dredge will have difficulty achieving grade. Overdepth dredging should not be an issue under this scenario.
  Recommendations: Reconsider using a hopper dredge for digging consolidated materials.

- **NSS1**
  Definition: New work dredging of soft dredged materials with mechanical equipment in sheltered/harbor conditions.
  Considerations: Mechanical equipment is especially well suited for this work, where there is limited maneuverability or dredging close to structures is required.
  Expectations: Expect a fair degree of accuracy in dredging depth, and a fairly smooth bottom when done, partly due to “smoothing” of the bottom with the dredge bucket. The dredge operator will disturb at least 2 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will disturb at least 4 ft below required depth to achieve grade.
  Recommendations: Dredged material should be characterized to a depth of not less than 6 ft below required depth if looking to characterize “disturbed depth.”

- **NSS2**
  Definition: New work dredging of soft dredged materials with a hydraulic cutterhead in sheltered/harbor conditions.
  Considerations: The cutterhead tends to disturb the bottom sediments several feet deeper than the target depth, as noted in the description of cutterhead dredges earlier in the document. Larger dredges tend to have larger cutterheads and will disturb the sediments to a greater depth. Soft sediments also tend to move around due to “plowing” of the bottom with the cutterhead.
  Expectations: Expect a fair degree of accuracy in dredging depth. The dredge operator will

disturb at least 3 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will disturb at least 5 ft below required depth to achieve grade.
Recommendations: Dredged material should be characterized to a depth of not less than 7 ft below required depth if looking to characterize "disturbed depth."

- **NSS3**
  Definition: New work dredging of soft dredged materials with a hopper dredge in sheltered/harbor conditions.
  Considerations: Hopper dredges tend to disturb the bottom sediments approximately 1 ft deeper than the target depth. Soft sediments also tend to move around due to "plowing" of the bottom by the draghead, but to a lesser degree than cutterhead dredges.
  Expectations: Expect a good degree of accuracy in dredging depth, with small ridges left behind between dragarm passes. The dredge operator will dredge approximately 1 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will still dredge approximately 1 ft below required depth to achieve grade.
  Recommendations: Dredged material should be characterized to a depth of not less than 1 ft below maximum pay depth if 2 ft of allowable overdepth is part of project design. If less than 2 ft of allowable overdepth is included, dredged material should be characterized not less than 3 ft below required depth.

- **NSR1**
  Definition: New work dredging of rock or hardpan with a mechanical dredge in sheltered/harbor conditions.
  Considerations: Mechanical equipment is well suited to dredge rock or hardpan. Rock and hardpan tend to excavate unevenly, due to large "chunks" being ripped up. If blasting is required prior to dredging, expect the depth of disturbance to be much greater than dredging depth.
  Expectations: Expect a moderate degree of inaccuracy in dredging depth, and an uneven bottom when done. The dredge operator will dredge at least 2 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 4 ft below required depth to achieve grade.
  Recommendations: Once bedrock or hardpan is reached, one should utilize geologic descriptions of the lithology to characterize the dredged material. In any event, one should ensure that the dredged material is characterized to a depth of not less than 6 ft below the required depth.

- **NSR2**
  Definition: New work dredging of rock or hardpan with a hydraulic cutterhead dredge in sheltered/harbor conditions.
  Considerations: For certain types of rock, hydraulic cutterhead dredges are adequately suited to dredge rock or hardpan. Rock and hardpan tend to excavate unevenly, due to large "chunks" being ripped up, but cutterheads tend to create smaller gouges than mechanical equipment. If blasting is required prior to dredging, expect the depth of disturbance to be much greater than the dredging depth.

Expectations: Expect a moderate degree of inaccuracy in dredging depth, and a somewhat uneven bottom when done. The dredge operator will dredge at least 3 ft below maximum pay depth (with an allowable overdepth of 2 ft) to ensure achieving required grade. If less than 2 ft of allowable overdepth is specified, the dredge operator will dredge at least 5 ft below required depth to achieve grade.
Recommendations: Once bedrock or hardpan is reached, one should utilize geologic descriptions of the lithology to characterize the dredged material. In any event, one should ensure that the dredged material is characterized to a depth of not less than 7 ft below the required depth.

SUMMARY: In collaboration with appropriate State and Federal resource and regulatory agencies, USACE will ensure that all applicable environmental compliance actions required for the dredging project have been identified and coordinated with those respective agencies. There are inherent excavation inaccuracies in the dredging processes. No dredge excavates a perfectly flat bottom exactly on the required project grade. Excavation accuracy relates to closeness of the dredge's completed work to the required project and/or overdepth grade as determined by after-dredge hydrographic surveys. Dredge excavation accuracies vary as a function of type of dredging equipment used (mechanical or hydraulic) and its respective interaction with site-specific physical conditions (tides, currents, waves), type and thickness of sediment or rock being dredged, channel design (water depth, side slopes, etc.) and the level of dredge crew skill and effort. Error components introduced by the dredge's positioning system and the hydrographic surveying techniques and equipment used to measure bathymetry will also contribute to overall excavation accuracy.

The Corps will characterize the total dredging prism, including authorized project dimensions, advance maintenance, paid allowable overdepth, and anticipated non-pay dredging. This technical note provides guidance on the requirements to adequately characterize all dredged material that could be removed during a federal dredging project. This guidance is meant to supplement Engineer Regulation (ER) 1130-2-520 (USACE 1996) and the Memorandum for Commanders, Major Subordinate Commands, "Assuring the Adequacy of Environmental Documentation for Construction and Maintenance Dredging of Federal Navigation Projects" (USACE 2006).

POINTS OF CONTACT: For additional information on depth of characterization, contact John Tavolaro (917-790-8403, *John.F.Tavolaro@nan02.usace.army.mil*), Joseph Wilson (202-761-7697, *Joseph.R.Wilson@hq02.usace.army.mil*), Timothy Welp (601-634-2083, *Timothy.L.Welp@erdc.usace.army.mil*), James Clausner (601-634-2009, *James.E.Clausner@erdc.usace.army.mil*), or Angela Premo (404-562-5130, *Angela.Y.Premo@sad01.usace.army.mil*).

This technical note should be cited as follows:

Tavolaro, J. F., J. R. Wilson, T. L. Welp, J. E. Clausner, and A. Y. Premo. 2007. Overdepth dredging and characterization depth recommendations. ERDC/TN EEDP-04-37, Vicksburg, MS: U.S. Army Engineer Research and Development Center.

REFERENCES:

American Society for Testing and Materials. 2005. *Standard terminology relating to soil, rock, and contained fluids, Designation D653-05.* West Conshohocken, PA.

Tavolaro, J. F., and S. R. Weinberg. 2006. An evaluation of overdepth dredging and its engineering and environmental implications: case studies from the northwest. *Western Dredging Association XXVI Technical Conference & 38th Texas A&M Dredging Seminar, June 25-28, 2006, San Diego, CA.*

U.S. Army Corps of Engineers. 1996. *Project operations: Navigation and dredging operations and maintenance policies.* Engineer Regulation 1130-2-520.

U.S. Army Corps of Engineers. 2002. *Hydrographic surveying.* Engineer Manual 1110-2-1003.

U.S. Army Corps of Engineers. 2006. *Assuring the adequacy of environmental documentation for construction and maintenance dredging of Federal navigation projects*. Guidance Memorandum.